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Chapter 7

General Discussion

This thesis set out to explore and describe perceptions of uncertain environmental health risks among different societal groups and to identify generic and case specific conditions for meaningful and effective communication about uncertain environmental health risks. Our research was guided by the following objectives:

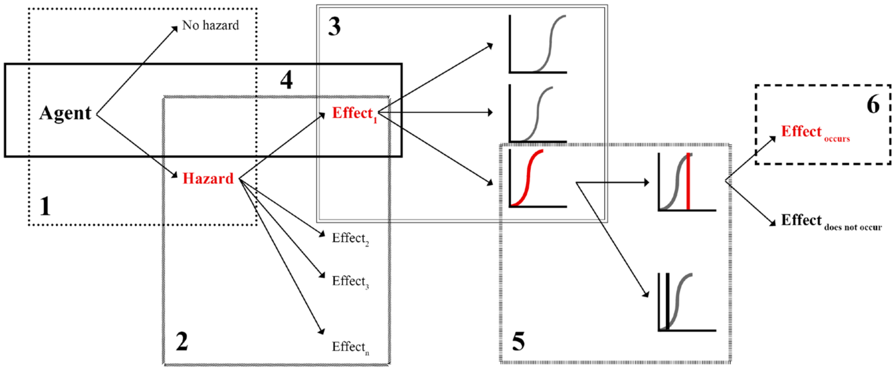
- **Characterize the concept of 'uncertain risk' in a typology that is appropriate for the environmental health domain and compare the typology with characterizations by different societal groups.**
- **Explore and describe the public's mental model of example cases of uncertain environmental health risks and identify points for improvement of current communication practices about uncertain environmental health risks.**
- **Compare the effectiveness of existing messages about example cases of uncertain health risks used in the media with messages that takes into account the public's beliefs.**

In this chapter, the main findings of this thesis are summarized and discussed. Three main themes are identified that help explain why there is a mismatch between appraisal of uncertain environmental health risks in different societal groups and communication approaches. Subsequently, methodological considerations are discussed and recommendations and suggestions for risk communication practice and research are provided. This chapter ends with a general conclusion.

Summary of main findings

Our conceptual review (chapter two) showed that the concept 'uncertain risk' refers to situations in which epistemic uncertainty (knowledge-related) in risk assessment prevent scientists from making conclusive statements about the presence or existence of environmental health risks. Uncertain environmental health risks can be characterized by six distinct epistemic uncertainties: about intrinsic properties of an agent (e.g. its structure or particle size); uncertainty about the nature of adverse effect (e.g. whether it can cause cancer or a headache); uncertainty about the nature of the hazard (e.g. its toxicity), uncertainty about the relationship between an agent and adverse effects (i.e. correlation of causation), uncertainty about actual exposure levels (e.g. whether exposure levels exceed a safe threshold), or uncertainty about the source of observed effects. These uncertainties are summarized in the typology presented in Figure 1. The type of epistemic uncertainty determines the overall level of uncertainty with regard to the presence or existence of risk; the more left the uncertainties are positioned in Figure 1, the more fundamental the uncertainties can be considered.

Figure 7.1. Schematic presentations of the six epistemic uncertainties that can characterize uncertain environmental health risks.



Note. 1. Uncertainty about intrinsic properties of an agent. 2. Uncertainty about the nature of adverse effects. 3. Uncertainty about the nature of the hazard. 4. Uncertainty about the relationship between an agent and adverse effects. 5. Uncertainty about actual exposure levels. 6. Uncertainty about the source of observed effects.

This typology was compared to characterizations of the concept of 'uncertain risk' by scientists and representatives of the general public, policy makers, and communication professionals in a qualitative study (chapter three). While there was overlap between groups, the concept elicited different meanings between and within groups. Different groups focused on different aspects of the concept , which can give rise to miscommunication between these groups. For example, scientists generally described the concept in terms of epistemic uncertainties, while members of the general public also described the concept in terms of unawareness of risks that are known to scientists, and a lack of control of the risk. Representatives from all groups commonly described the concept in terms of uncertainties that imply the understanding that a risk exists (e.g. 'uncertainty about the magnitude of the risk'), while the concept intends to convey a risk is not conclusively established.

Results of a qualitative study into public appraisal of uncertain risks associated with the presence of chemical substances in food (chapter four) showed that participants did not have relevant knowledge about the chemical substances and based their judgments on the interpretation of, and associations with, textual information about the cases addressed (BPA, MOAH or SAS). Results show that participants' understanding of epistemic uncertainty was often not in line with the scientific meaning. Participants were more apprehensive about the presence of the chemical in food than worried about (the risk of) experiencing health complaints. Survey results (chapter five) confirmed these findings and showed that the public distinguishes between appraisal of the hazard (in terms of severity of the presence of a chemical in food) and risks (in terms of magnitude of the risk for health). Additionally, while highly related, results showed public beliefs about exposure to a chemical and the toxicity of that chemical often do not correspond . First, a large majority (around 90%) of the public is well aware that the frequency, amount and duration of exposure determine whether a chemical constitutes a risk. At the same time, a significant minority beliefs that all chemicals are equally harmful. Additionally, results suggested that the higher people value certainty about food safety and the less they evaluate scientific uncertainty as acceptable, the more serious they appraised the presence of a chemical in food.

The results of our experimental study (chapter six) showed that incorporating the public's mental model of chemical risks (i.e. beliefs about factors that determine whether a chemical constitutes a health risk) in descriptions of epistemic uncertainty is not sufficient to improve public understanding of uncertainty. Moreover, results showed that some individuals had a better understanding of epistemic uncertainty than others. This particularly applied to individuals who believe scientific knowledge is tentative and open to advancing insights (as compared to certain and fixed), individuals who believe knowledge is justified through expert knowledge and skill (as compared to personal insights and experience), or individuals who are not interested in food safety (as compared highly interested in food safety).

Discussion of main findings

The results of the different chapters of this thesis can be summarized in three main themes. First, results show there is a mismatch between the use and the understanding of risk terminology. Second, results show that scientific information on uncertain environmental health risks often does not align with public perspectives on hazards, risks, and uncertainty . Finally results show that current practices in uncertainty communication leave much room for (mis)interpretation of the evidence base for risk.

A mismatch between the use and understanding of risk terminology

Scientific experts often trivialize the role of semantics in risk communication [see e.g. (1)]. The use of risk terminology is therefore often not given much consideration in public risk communication. Throughout our research we however found that risk terminology central to environmental health risk communication (e.g. 'exposure', 'uncertain risk', 'risk', 'safe', 'harmful') can have different meanings for different individuals, and (thereby) elicit different associations. These different 'semantic mental models' (i.e. perspectives on the meaning of, and associations with, risk terminology) from groups and individuals (e.g. scientists, general public, communication professionals) cause a mismatch between the use of terminology in risk communication and the understanding of terminology by, for example, the general public[(2, 3)]. Because people also use their 'semantic mental models' to make sense of new information[(4)] attention needs to be paid to the discrepancies.

Our research showed that within the scientific community discrepancies and miscommunication occur when scientists advocate different risk (assessment) models, that use the same terminology with different meanings. For example, scientists who advocate the IRGC risk governance model[(5)], use the term 'exposure' in a way that excludes aspects of dose-response, while scientists who advocate toxicological risk assessments models use the term in a way that includes aspects of dose-response[6, 7]. Also, different models describe risk criteria (e.g. toxicity) in different steps of the risk assessment process (e.g. in hazard identification and estimation (IRGC) or in effects assessment (toxicological models))[5-8], which – whilst using the same data – lead to different conclusions on where uncertainty manifest itself within the risk model[9].

Differential use and characterizations of the term 'uncertain risk' can also lead to miscommunication. For example, from statement like 'the risk is uncertain' or 'a risk cannot be excluded' it is unclear what type of epistemic uncertainties prevent scientists from conclusive statements about the probability of occurrence of effects (see also Figure 1) [also see 10, 11, 12]. Additionally, the general public may not characterize the concept of 'uncertain risk' based on epistemic grounds; may not differentiate between the concept of 'uncertain risk' and 'risk' at all; and may associate 'risk' with 'danger' or 'something that can go wrong or right'. This way, tentative statements like 'A risk cannot be excluded' or 'the risk is uncertain' can elicit associations with conclusive danger.

As illustrated by the examples above, the term 'risk' is often used in communication about uncertain environmental health risks. While there is no universal definition of 'risk', and while there are many different perspectives on the concept[13-24], in Dutch (governmental) risk communications 'risk' is treated – in accordance with the B1 classification of the Common European Framework of Reference for Languages (CEFR)(25) – as a word that is consistently understood by more than eighty percent of the population. However, results of chapter two show that the meaning and associations people ascribe to the concept are frequently not in line with the intended meaning. Additionally, also in the context of uncertain environmental health risks, 'risk' is frequently used as a synecdoche, to refer to either (uncertainty about) a probability of adverse effects, or only to (uncertainty about) a hazard[see e.g. 1, 26]. For example, in the sentence "One of the risks is the release of carbon monoxide" 'risk' refers to a health hazard (i.e. carbon monoxide), while in the sentence "The risk of 1 in 100 is relatively low when compared to birth defects caused by other viral infections" 'risk' refers to the probability of occurrence (or: chance) of adverse effects (i.e. 1 in 100 chance if birth defects). The differential use, meanings of, and associations with the term 'risk' [1, 26], and the tendency of the general public to evaluate risks along different aspects than scientists [see e.g. 27], raises the question whether 'risk' should be considered as a word that is consistently understood by the majority of the (Dutch) population. As risk is also a pejorative the question can further be raised whether the term should be avoided in risk communication, in particular when there is no conclusive evidence for the existence of environmental health risks.

'Safe' and 'harmful' – words also central to environmental health risk communication – raise similar issues. For example, while the term 'safe' generally means that (with 'normal' use or exposure) exposure levels are below a safe threshold (i.e. the absence of a risk)[28, 29], members of the general public may believe that 'safe' means a substance does not have the properties to cause adverse effects (i.e. the absence of a hazard). They may therefore choose not to take mitigation measures, even when they are frequently (e.g. occupationally) exposed. If the media eventually clarify that the substance does have hazardous properties, the initial misunderstanding can undermine public trust in the government, even if there was no risk to health[30]. Finally, instead of talking about 'chemical substances', participants in our study often talked about 'harmful (in Dutch: 'schadelijke') substances'. Only a minority defined the harmfulness of a substance in correspondence with the scientific understanding; by the toxicity or amount of a chemical substance needed to cause adverse effects (e.g. one tea spoon or five tea spoons)[31]. Others believed the harmfulness of a substance was defined by the number of people affected by the chemical or by the severity of the effects a chemical can cause (e.g. cancer or a headache). Spelling out the intended meaning by either the amount needed to cause adverse effects (i.e. the toxicity); by the number of people affected; or by the severity of the effects a chemical can cause (e.g. cancer or a headache) therefore likely improves consistent understanding. When the meaning of terminology is not made explicit, miscommunications can go by unnoticed and can ultimately lead to unintended and badly informed (policy) decisions[32].

Aligning with public conceptualizations of risk terminology is also important because it can affect whether communication will actually reach the public at all. That is, in today's society the Internet is likely is the first source of information on (environmental) health risks for many people[33]. Risk communication is thus increasingly demand-driven; driven by people's search terms and queries used to search for information online. When there is a mismatch between search terms used by the public, and terminology used in online information by trusted sources, this can cause people to only be confronted with information from less trusted, often partisan and alarming, voices. Using the public's vocabulary (e.g. using 'eating' or 'drinking' to describe exposure through food, or to use 'danger' next to 'risk') in communications about uncertain environmental health risks will likely improve chances that information fits people's search queries, thereby increasing the chance of information of trusted sources being presented in (the top of) the search results page.

Scientific information on uncertain environmental health risks often does not align with public perspectives on hazards, risks, and uncertainty

From our and previous research[34-39, 2, 40-43] it is evident that people judge and appraise uncertain environmental health risks based on a complex cognitive network (i.e. their mental model) of expectations, values, beliefs and attitudes about the issue at hand. Our research shows that in the context of uncertain environmental health risks the public distinguishes between appraisal of hazards and appraisal of risks: People are generally more apprehensive about the hazard (i.e. the presence of a chemical in food) than the risk (i.e. the probability of experiencing health effects)[see also 44]. Some experts however believe the public is deficient in their understanding of hazards and associated risks, and that the public does not clearly differentiate between toxicological hazards and risks[40, 45-47]. Consequently, a clear distinction between hazard and risk is generally not made in current risk communication practices(see e.g.

26). However, our results showed that people are well aware that a chemical only constitutes a risk if exposure exceeds a certain threshold in terms of frequency and amount[see also 48, 49], and that people use estimates of frequency and amount of personal exposure to determine whether they are at risk, regardless of whether the risk is conclusive established by scientists. However, while scientists use exposure estimates to determine whether and to what degree a hazard constitutes a risk, results presented in chapter three and four show that public appraisal of hazards (in terms of severity) and risks (in terms of magnitude) is not associated with beliefs about exposure. Instead, people based their case-specific judgments on domain-wide values and beliefs(2) (e.g. 'it should be 100% certain that chemicals in food are safe to eat' and 'all chemicals are harmful') and used these perspectives to make sense of the new information(4). Hazard specific properties (e.g. whether food packaging is made of plastic of cardboard) and information provided in the text (e.g. the mentioning of specific health effects) [3, 50, 51] also affected appraisal. Providing formal risk assessment knowledge (e.g. about exposure) may thus support people to judge whether they are at risk, but likely does not support people's appraisal of uncertain environmental health risks in terms of severity of the hazard or magnitude of risk.

In line with the 'congruence principle' or 'congruity hypothesis'[52, 53], results from chapter four suggest that people express unfavorable responses towards uncertainty about food safety, when the level of uncertainty that is communicated (i.e. the actual uncertainty) does not match the level of uncertainty that people expect[54-56]. This is likely associated with a general discrepancy between the level of certainty people expect from risk assessment science and the level of certainty that risk assessment can realistically deliver[57], and with the general belief that science 'provides definitive answers'[58, 59]. The mismatch between expected and actual uncertainty poses a particular challenge to effective communication about uncertain risks. As our results showed people generally do not expect epistemic uncertainty[see also 60], any communication about uncertainty about environmental health issues can have detrimental effects on people's appraisal.

Thus, some people do not believe or expect that scientific knowledge and conclusions about safety will change. These beliefs affect people's evaluations of information on epistemic uncertainty about risks[61-64]. For example, research has shown that people who perceive knowledge as more tentative and open to advancing insights, have a more positive view of emerging technologies like nanotechnology[65]. Alternatively, when people believe that knowledge is unchanging and consists of isolated facts, they may have great difficulty in processing information on epistemic uncertainty about risks[64, 66, 67]. Results from chapter 6 indeed show that beliefs about the nature of scientific knowledge (e.g. about the tentativeness of scientific knowledge or the justification of knowledge) affect how people evaluate information on epistemic uncertainty[see also 64]. This is likely caused by people's tendency to biased information processing. For example, studies have shown that unwarranted confidence in one's own judgments and evaluations (called the 'overconfidence bias), results in biased information processing[37, 68]. Because people who put unwarranted confidence in one's own judgments likely also put less trust in scientific evidence and methods[61, 62] they may be particularly skeptical of (scientific) epistemic uncertainty, leading them to discount uncertainty information. People also have the tendency to only select and interpret information that support their existing worldviews (called the confirmation bias). This way, people who believe knowledge about food safety is certain and fixed may believe that information on uncertainty is unreliable and discount information on epistemic uncertainty[69, 70].

Contrary to expectations[71-73], results also showed that individuals who are not interested in food safety generally understand information on epistemic uncertainty (about food safety) better than individuals who were highly interested in food safety. Arguably, this is explained by the assumption that people who are highly interested in food safety are also more concerned about food safety and have negative attitudes towards the presence of chemicals in food [49, 74-76]. Their mental models likely make them evaluate uncertainty information in a biased fashion, in which they discount information on uncertainty about risks to arrive at a preferred conclusion (e.g. 'all chemicals are harmful'). People who are not interested in food safety are likely less guided by their prior beliefs and attitudes and are therefore more 'neutral' in their evaluation[34, 77, 78].

Current practices in uncertainty communication leave much room for misinterpretation of the evidence base for risk

In order to make informed decisions people want to be informed about scientific uncertainty about risks, even when there is uncertainty over whether a problem actually exists or not[79-82]. Communication about uncertain environmental health risks should enable people to draw the correct conclusions about the evidence base for the presence of risks[83]. Results of this thesis show that indicators of epistemic uncertainty in risk assessment such as 'the substance possibly has effects on the immune system' or 'the risk is uncertain' can cause people to misinterpret the evidence base for possible health risks of environmental agents[84-92]. For example, people frequently interpreted the sentence 'BPA possibly has effects on the immune system' as an indication that there is conclusive proof BPA can affect the immune system, and that uncertainty exists about who will experience the effects. The sentence however meant to convey that uncertainty exists about whether BPA has the intrinsic properties to cause these adverse effects. Stahl & Cimorelli[93] state that determining whether this ambiguity in uncertainty information is acceptable depends on the (amount of) information that, when newly acquired, would change the meaning of the communication. In this light, the ambiguity can be considered unacceptable: When it is clear uncertainty exists about fundamental aspects of the hazard (e.g. about an agent's intrinsic properties) rather than the risk (e.g. about people's exposure levels) some people may decide not to take precautionary actions, while others may want to act immediately to take away uncertainty[10, 29, 32, 56, 94-96]. Moreover, ambiguity can be considered unwanted as misinterpretations of epistemic uncertainty will likely influence perceptions of (food) safety[45] and trust in regulating authorities[97, 98], and responses of individuals at the extremes of interpretation (e.g. individuals who believe there is conclusive evidence for serious health risks) can greatly affect the societal response to the uncertain environmental health risk[99-101].

Misinterpretation of the evidence base can also be caused by the use of risk terminology and contextual information. People may understand scientific terminology and phrasing in a manner that denotes conclusive knowledge while it is intended to denote epistemic uncertainty. For example, talking about 'risk' in the context of environmental health, implies that people are exposed, and that the thing they are exposed to has the properties to cause adverse effects (i.e. the hazard). After all, when there is no exposure, or when there is no hazard, there is no risk[13, 102]. However, 'risk' and 'hazard' are often used interchangeably depending on the perspective (e.g. economic interest, or a watchdog role) of societal groups[26]. Similarly, our results and results by Wiedemann and colleagues[90] show that stating that a substance is 'possibly carcinogenic' (meaning there is epistemic uncertainty whether the substance has the properties to cause cancer) can cause people to believe that there is conclusive evidence a substance has the properties to cause cancer, and there is uncertainty about who will suffer the effects[cf. 103]. Providing contextual information on, for example why something is being researched (e.g. because a substance is 'non-degradable' in the gastrointestinal tract), or what specific adverse effects are being researched (e.g. ' on reproduction and development') can also evoke incorrect ideas about the evidence base 'or else they wouldn't have mentioned it'. These examples make clear that the use of risk terminology and contextual information can make it difficult for the public to differentiate between uncertainties and that they contribute to unwanted conclusions about the available evidence regarding the presence and existence of risk[104, 105].

Methodological considerations

The methodological strength of the research presented in this thesis is that we used conceptual, qualitative and quantitative methods. Our conceptual research provided the means to apply a systematic and standardized approach to a concept that would otherwise be difficult to explain. By first conducting in-depth interviews with target populations, we gained insights that are likely overlooked in quantitative studies. For example, respondents used their own words to explain how they understood risk terminology and used their own words to describe their values, beliefs, attitudes and expectations. Through our qualitative study we found that the meaning people give to scientific terms and phrases often does not correspond to the scientific concept. This gave us a great advantage in designing the questionnaire.

The applied methodology in this thesis also has some limitations. For example, the focus on the perspectives on general public in chapters four, five and six limits the generalizability of the findings to other societal groups. For example, policy makers likely have different (professional) perspectives on the cases addressed. We chose to focus on the general public, as results from chapter two showed their perspectives on uncertain risks deviated most from that of scientists. We therefore believed that insights from an in-depth analysis of the public understanding would benefit effective risk communication most. Additionally, through the cases selected we focused on the food domain, and in essence only highlighted two out of six identified situations in which environmental health scientists refer to uncertain risk. In different domains, different cases and in the context of different uncertainties other perspectives may apply, for example on the acceptability and expectations of scientific uncertainty[see also 64]. This may limit the generalizability of the specific results described in these chapters to other environmental health topics such as the physical environmental factors or infectious diseases[106]. However, the conceptual methodology applied in this thesis can also be applied to other environmental health (e.g. the domain of infectious and communicable diseases) and non-environmental health domains to identify epistemic uncertainties that characterize uncertain risks in other domains. Finally, we used an online panel in our quantitative research. For our sample we drew a stratified random sample in terms of the distribution of gender, age, education level and geographical location in the Netherlands according to Statistics Netherlands (2018). However, because strata are not mutually exclusive, we cannot exclude that sampling bias may have occurred on the selected and other individual characteristics.

Recommendations to foster effective communication about uncertain environmental health risks

Uncertainties inherent to contemporary science and risk assessment are increasingly subject to public scrutiny due to transparency in, and communication about, regulatory decision making[81, 107-109]. How people judge and respond to this uncertainty and to uncertain environmental health risks in general, depends on how uncertainty is communicated and interpreted[110]. This thesis suggest that effective communication about uncertain environmental health risks can be fostered by developing information that facilitates understanding of risk terminology used in communication, that aligns with public perspectives on hazards, risks, and uncertainty, and that minimizes room for (mis)interpretation of the evidence base for risk.[see also 108, 111, 112]. Based on the research presented in this thesis six recommendation are presented that can help achieve these goals:

1. **Develop information on uncertain environmental health risks deliberatively, by involving representatives of target audiences. A case specific approach is recommended.**

For example, interviews or focus groups with representatives of target audiences about specific environmental health issues will alert communicators to relevant values, beliefs, attitudes, expectations and concerns that otherwise will likely be missed[see also 113].

2. **Take into account different ‘semantic mental models’ of risk terminology and explicitly reflect on whether risk terminology used in communication has the same meaning for the target audience as for the communicator.**

When knowledge about people’s conceptualizations is lacking, or when there is doubt over people’s conceptualizations, different terminology should be used, or the intended meaning should be described to avoid unintended associations and consequences[2, 3]. For example, does 'safe' have the same meaning for the intended audience as is intended in the communication?[see also 28, 35, 114, 115]

3. **Avoid ambiguous indicators of epistemic uncertainty in risk assessment and communicate epistemic uncertainties as clear and exact as possible to all audiences, including the general public.**

For example, avoid stating 'the substance possibly has effects on X' when there is epistemic uncertainty about whether a substance can cause adverse effects. Instead it is better to state that 'it is unclear whether the substance has properties to cause X'.[see also 92, 112].

4. **Distinguish between communicating information that supports appraisal of the hazard and communication that supports appraisal of the risk.**

For example, in the context of chemical substances in food communication needs to address the mismatch between expected and actual uncertainty (see below) to support appraisal of the hazard, and the misconception that all chemicals are (equally) harmful to support appraisal of the risk. While our research showed that a strict reliance on a knowledge deficit model in public communication about uncertain environmental health risks is inappropriate[116], addressing (negative) attitudes (e.g. towards chemical substances) will likely have more effect on public appraisal than providing additional formal – scientific – knowledge about risk[48, 81].

5. **Identify, and align with, the (level of) uncertainty people expect. When there is a mismatch with the actual (level of) uncertainty, address the mismatch in the communication.**

For example, in the context of chemical substances in food previous research has shown that increasing knowledge about the (limits of) toxicological risk assessment and regulation process (for example through information videos, leaflets or pamphlets) can narrow the gap between expected and actual uncertainty[117], and may also lower risk perception and increase acceptance of uncertain risks from chemicals in food[118, 119, 74, 120].

6. **Reflect on how audiences can evaluate the terminology used in communication in terms of epistemic uncertainty and whether contextual information can evoke incorrect conclusions about the evidence base.**

For example, using the phrase 'possibly carcinogenic' can cause people to overestimate the evidence base for cancer risks[see also 89, 100, 105]. When knowledge about people's conceptualizations of knowledge and epistemic uncertainty is lacking, or when there is doubt over people's conceptualizations, different terminology should be used, or the intended meaning should be described to avoid unintended conclusions about the evidence base for risk [see also 2, 3, 35, 90, 115, 121].

Recommendations for future risk communication research

Uncertain environmental health risk will likely continue to be topic of scientific interest in the future. For example, because new technologies and new applications of existing novel technologies (e.g. nano- or biotechnology) with uncertain impacts on human health will continue to be developed. The results presented in this thesis provide several points of interest to pursue in future research, which are outlined in four recommendations below:

1. **Spell out the contextual meaning of risk terminology like 'risk' in the design of survey items.**

The term 'risk' is frequently used without further thinking in items to measure, for example, risk perception. The research presented in this thesis show that 'risk' and other risk terminology can elicit different responses in individuals. Clearly explaining the dimensions of a 'risk item' ensures consistent interpretation by respondents and thereby increases the value and reliability of results.[122] For example, from a response to an item stating 'How large do you estimate the risk of [X] (for your health)?' it is unclear what dimension of risk (e.g. probability, seriousness, or something that people value) an individual has evaluated. Even when response options are categorized as 'highly unlikely – highly likely' or 'not at all serious – very serious' it is better to spell out the dimensions to reduce ambiguity. That is, 'How big do you estimate the chance of experiencing adverse effects from [X]' when you are interested in a perception of probability and 'How serious do you think it is that there is a probability [X] will cause adverse effects?' if you are interested in perception of severity of the probability or 'How serious do you think it is that [X] has the properties to cause [adverse effect Y]'? if you are interested in perception of severity of the hazard. [123-125]

2. **Study how public understanding of epistemic uncertainty, and study the effect of understanding of epistemic uncertainty on public appraisal of hazards and risks.**

More research into public understanding of epistemic uncertainty can contribute to a better understanding of how effective communication about uncertain environmental health risks can be improved consistently. Additionally, it can provide valuable insights in whether the understanding of epistemic (e.g. whether knowledge about a chemical's hazardous properties is conclusive or uncertainty) affects how hazards and risks are appraised.

3. **Study public epistemological beliefs in other environmental health domains.**

While research into (the domain specificity) of public epistemological beliefs is generally conducted in the context of academic performance[64, 126], insights in people's beliefs and expectations of scientific knowledge in different environmental health domains (e.g. infectious diseases or physical environmental factors) can help understand and explain how these beliefs influence comprehension of epistemic uncertainty[67] and acceptability of epistemic uncertainty in these different domains[126].

4. **Study the terminology and queries people use to search for environmental health risk information on the internet, and study whether there are inequalities in the (credibility of) provided information between people using different search terms and queries.**

All efforts in improving risk communication about uncertain environmental health risks are in vain if the carefully designed information is not found.

General conclusion

The research presented in this thesis shows that ill-advised communication about uncertain environmental health risks can cause scientific knowledge to be misjudged, and lead people draw incorrect conclusions about the evidence base for the presence of risks. This ultimately results in poorly informed judgment and decision-making about uncertain environmental health risks. This thesis provides a clear typology of the concept of uncertain risk, which helps to identify and deal with epistemic uncertainties in risk communication in a systematic and standardized way. We demonstrated that people evaluate uncertain environmental health risks based on a trade-off between characteristics of the hazards and characteristics of the possible risks and that the belief that all chemicals are equally harmful and a mismatch between actual and expected uncertainty have detrimental effects on hazard and risk appraisal. Efforts should be made to facilitate a better match between the use and understanding of risk terminology, to align with relevant public perspectives on hazards, risks, and uncertainty, and to minimize room for (mis)interpretation of the evidence base for risk. These insights help facilitate a better and science-based match between appraisals of uncertain environmental health risks in different societal groups and risk communication approaches.

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